First High Q^2 ^{3}He Form Factor Measurements using Polarization Observables

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July 24th 2019

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  - FFs extracted via polarization observables vs. unpolarized Rosenbluth separations disagree.
  - Disagreement is worse at high Q^2.
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- Double-polarization measurements have also shown divergent results from theoretical predictions in past ^{3}He experiments (Mihovilovič *et al*. 2019; Mihovilovič *et al*. 2014).
- The double-polarization asymmetry (polarized electron beam and polarized ^{3}He target) is proportional to the product of F_{ch} and F_m.
  - Zeros of the asymmetry are the FF diffractive minima.
  - Constrain minima locations.
  - Hypothesis test theoretical models.

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- All experimental data either from Rosenbluth separation techniques or cross section world data fitting with a FF parametrization.

$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{exp}} = \left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}} \frac{1}{1+\tau}\left[G_E^2\left(Q^2\right) + \frac{\tau}{\epsilon} G_M^2\left(Q^2\right)\right] \quad (1)$$

  - With $\epsilon = \left(1 + 2(1+\tau)\tan^2\left(\frac{\theta}{2}\right)\right)^{-1}$ and $\tau = \frac{Q^2}{4M^2}$, where θ is the scattering angle of the electron.

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$$\left(\frac{d\sigma}{d\Omega}\right)_{\text{r}} = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{\text{exp}}}{\left(\frac{d\sigma}{d\Omega}\right)_{\text{Mott}}}\epsilon(1+\tau) = \left[\epsilon G_E^2\left(Q^2\right) + \tau G_M^2\left(Q^2\right)\right] \quad (2)$$

  - By plotting $\left(\frac{d\sigma}{d\Omega}\right)_{\text{r}}$ against ϵ the slope of the line gives G_E^2 and the y-intercept gives τG_M^2.
- Rosenbluth separations take significant beam time and struggle near the diffrative minima.

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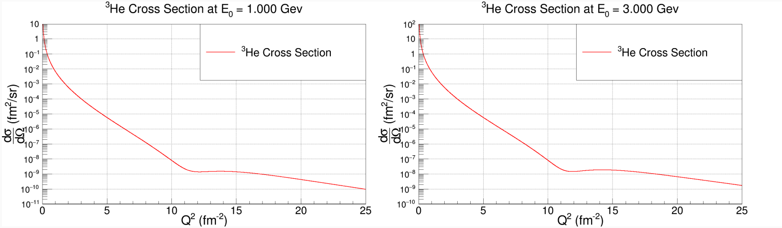
- ^{3}He cross section at 1 GeV and 3 GeV.



(a) ^{3}He cross section at 1 GeV. **(b)** ^{3}He cross section at 3 GeV.

Figure 1: Plots of the ^{3}He cross section at two different energies. Form factor parametrizations from Reference (Barcus 2019).

- Can sharp FF minima fit relatively shallow cross section minima well?

F_{ch}

- Plot of ^{3}He F_{ch} with four theory curves.
  - 'Conventional' theoretical approach, two χEFT predictions, and a covariant spectator theorem model (Marcucci *et al.* 2016).

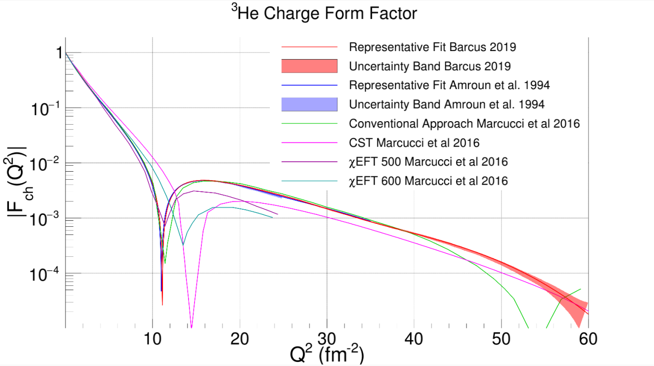


Figure 2: ^{3}He F_{ch} SOG fits and uncertainty bands from References (Amroun *et al.* 1994; Barcus 2019) along with four theoretical predictions from Reference (Marcucci *et al.* 2016). Note that F_{ch} is plotted here and $F_{ch} = G_E$.

- Plot of ^{3}He F_m with four theory curves.

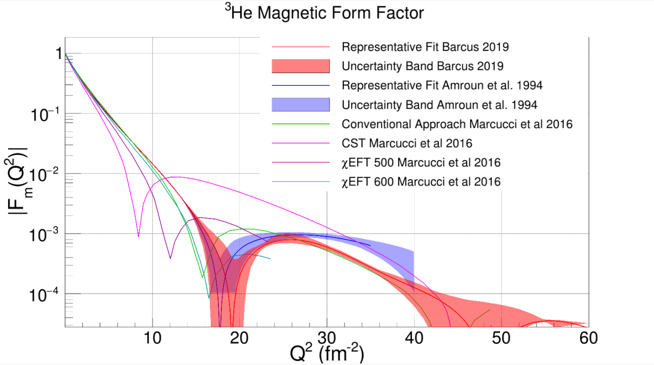


Figure 3: ^{3}He F_m SOG fits and uncertainty bands from References (Amroun *et al*. 1994; Barcus 2019) along with four theoretical predictions from Reference (Marcucci *et al*. 2016). Note that F_m is plotted here and $F_m = G_M/\mu$, where μ is the ^{3}He magnetic moment.

- Theory predicts minimum at significantly lower Q^2 than measured.

Double-Polarization Asymmetry

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- The double-polarization asymmetry is given by:

$$A_{phys} = \frac{-2\sqrt{\tau(1+\tau)}\tan\left(\frac{\theta}{2}\right)}{G_E^2 + \frac{\tau}{\epsilon}G_M^2}\left[\sin(\theta^*)\cos(\phi^*)\,G_E G_M + \sqrt{\tau\left[1+(1+\tau)\tan^2\left(\frac{\theta}{2}\right)\right]}\cos(\theta^*)\,G_M^2\right] \quad (3)$$

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- The measured observable is given by (4) and relates to the true asymmetry by (5).

$$A_{meas} = \frac{N^+ - N^-}{N^+ + N^-}, \quad (4) \qquad A_{meas} = P_t P_l A_{phys}, \quad (5)$$

  - N^+ (N^-) is the normalized counting rate for positive (negative) beam helicity.
  - P_t and P_l are the degrees of polarization of the target and beam.

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  - The zeros of the asymmetry correspond to the FF minima.
- Hypothesis test theoretical predictions.
  - Take G_E and G_M from theory and calculate/plot theory asymmetries.
- New independent tool to map FFs without the issues of unpolarized Rosenbluth measurements.

Double-Polarization Asymmetry Cont.

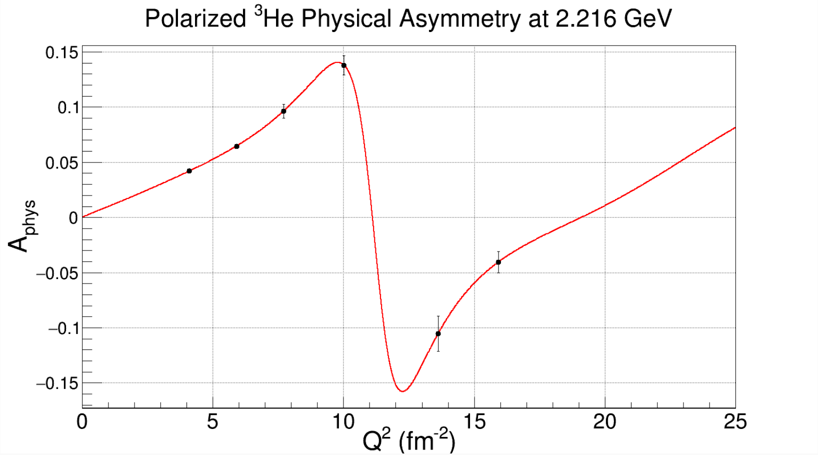

Figure 4: Double-polarization asymmetry at 2.216 GeV using the SOG fits in Reference (Barcus 2019). The points show the statistical uncertainty of the mean of each kinematic setting.

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- Uses ^{3}He target developed for E12-06-110 and E12-06-121.

Length [cm]	Max Current [μA]	Target Polarization	Beam Polarization
40	30	55%	85%

Table 1: Expected ^{3}He Target Characteristics

Proposed Procedure Cont.

- Parasitically make measurements at 2.216 GeV when experiment E12-06-121 (Sawatzky *et al*. 2006) takes data on beam-target polarization product.

	E_{beam} [GeV]		θ [°]	Q^2 [fm^{-2}]	Estimated Cross Section [mb/sr]	Rate [Events/hr]	Time [hr]
SHMS	2.216	k1	11	4.57	4.39×10^{-4}	2,605,270	1
		k2	13	6.34	5.14×10^{-5}	305,609	1
		k3	15	8.38	4.37×10^{-6}	25,946	1
		k4	17	10.66	2.22×10^{-7}	1,319	10
		k5	19	13.18	5.97×10^{-8}	355	11
HMS	2.216	k6	21	15.93	3.99×10^{-8}	427	24

Table 2: Spectrometer Central Kinematics

- High rate kinematics not statistics limited $\rightarrow$ check systematics.
- Low Q^2 points will determine product of beam-target polarization.

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- In collaboration with d_2^n we proposed to measure the double-polarization asymmetry of ^{3}He over a range of Q^2.
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  - Parasitically uses time already allotted for measuring beam-target polarization product.
- This will be the first high Q^2 measurement of ^{3}He FFs using polarization observables.
  - Constrain the locations of the FF diffractive minima.
  - Provide new method to hypothesis test theory predictions.
  - Determine if polarization observables agree with unpolarized Rosenbluth results.
  - Help explain the discrepancies between theoretical predictions and experimental measurements of the ^{3}He FFs.
- History has shown that polarization measurements can reveal problems with cross section extracted FFs (Jones *et al.* 2000).

Acknowledgments

- Thanks to the A_1^n/D_2^n collaboration for welcoming us and supporting our run group proposal.
- Thanks to Shujie Li for running the MC simulations for rate estimates and many other contributions.
- Thanks to Brad Sawatzky for welcoming us to the collaboration and his guidance through this process.
- Thanks to Doug Higinbotham for organizing this process and keeping this proposal going year after year.
- Finally, thanks also to all those who worked to develop this proposal in the past including R. E. McClellan, J. Bericic, V. Sulkosky, T. Averett, and S. Sirca.

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